UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION 5
77 WEST JACKSON BOULEVARD
CHICAGO, IL 60604-3590

EPA Region 5 Records Ctr.
226790

REPLY TO THE ATTENTION OF

JAN 30 2003

SE-5J

VIA FACSIMILE (847) 279-2510 AND U.S. MAIL

Mr. Richard Berggreen
STS Consultants, Ltd.
750 Corporate Woods Parkway
Vernon Hills, Illinois 60061

RE: Lakeshore East Borehole Calculation Adjustment for Water

Dear Mr. Berggreen:

Based on your concerns, U.S. EPA has recalculated the adjustment made for water surrounding the borehole work on October 29, 2002. Enclosed is a copy of a memorandum dated January 24, 2003, which shows that none of the nine data points exceed the modified cleanup criterion. Therefore, you may disregard the earlier letter dated January 7, 2003 regarding calculation adjustment for water. Please note we normally do not include internal correspondence, however, for this situation, we made an exception so all involved could follow the rationale and view the calculations.

If you would like to discuss this matter further, please contact me at (312) 886-3601 or Mary Fulghum, Associate Regional Counsel, at (312) 886-4683.

Sincerely,

Verneta Simon

Verneta Simon
On-Scene Coordinator

Enclosure

cc: Naren Prasad, Chicago Department of Environment

bcc: Mary Fulghum C-14J, w/enclosure
Larry Jensen, SMF-4J, w/enclosure
Cathy Martwick, C-14J, w/enclosure
Fred Micke, SE-5J, w/enclosure
Linda Nachowicz, SE-5J, w/o enclosure
Debbie Regel, SE-5J, w/o enclosure

U.S. ENVIRONMENTAL PROTECTION AGENCY
SUPERFUND DIVISION
77 WEST JACKSON BOULEVARD
CHICAGO, ILLINOIS 60604

DATE: January 24, 2003

SUBJECT: Adjustment of Criterion for Borehole Measurements Below Groundwater at Lakeshore East Due to Water Around Borehole Casing, Revised

FROM: Larry Jensen, CHP
Regional Radiation Expert
Emergency Response Section #3

TO: Fred Micke
On-Scene Coordinator
Emergency Response Section #3

Verneta Simon
On-Scene Coordinator
Emergency Response Section #3

During the Removal Action at Lakeshore East, the Potentially Responsible Party's contractor, STS Consultants, reached groundwater before they were sure they had completely removed all the thorium contaminants. Because of the difficulty of locating any thorium materials under water and because of the difficulty of ensuring that any contaminants were removed, STS drove four borings into the area and conducted gamma logging (see attached map for locations).

Their data was based on calibrations for a borehole casing of steel pipe but did not allow for water between the casing and the surrounding soil. As a result, their coefficient corresponding to the Lakeshore East cleanup criterion (5396 counts per 30 seconds for 7.2 picocuries per gram) was not directly usable for determining if subsurface material exceeded the criterion for cleanup.

In this memo I describe how I adjusted their coefficient to include 3 inches and 1.5 inches of water absorber (two cases as requested by Fred Micke, On-Scene Coordinator). The calculation with 3 inches of water assumes the pipe is leaning against one side of the boring wall and all the water is on one side. The calculation for 1.5 inches assumes the pipe is down the center of the borehole.

The calculation was also adjusted to account for the fact that the calibration was done to 7.2 pCi/g while the Lakeshore East cleanup criterion is 7.1 pCi/g.

The new coefficient is 5336 counts per 30 seconds per 7.1 pCi/g for 3 inches of water and 5216 counts per 30 seconds per 7.1 pCi/g for 1.5 inches of water.

As a result of this information, no downhole logging count rates were deemed to exceed the equivalent Lakeshore East cleanup criterion at 7.1 pCi/g.

Adjustment of Cleanup Criterion for 3 Inches and for 1.5 Inches of Water Absorber

Overview of Adjustment

When gamma rays impact a medium, such as water, there will be absorption but there may also be some enhancement (or buildup) due to scattering of the gamma rays as they collide with the absorber. The result is found by multiplying the incoming level by an absorption factor and by a buildup factor. The effect will vary depending on the energy of the gamma ray. The total or net effect will be the sum of the individual energy-dependent values.

The equation for this calculation is not complicated. However, the parameters that go into the equation cannot be determined by direct calculation, but must be interpolated from data tables. Most of the work necessary to calculate an answer for this problem was spent interpolating from available data sets.

The result was a modified parameter corresponding to a count rate per 30 seconds for the site cleanup criterion, 7.1 picocuries per gram (pCi/g).

Method for Calculation of Adjusted Criterion Count Rate

The fundamental equation for this calculation was taken from the Radiological Health Handbook published by the Department of Health, Education and Welfare. However, it can be found in academic and reference texts, as well as on the internet. Specifically,

$$\mathbf{X = X_o * B * exp(-ux)} \qquad \textbf{Equation 1}$$

where

X = the corrected count rate (counts per 30 seconds, c/30s)

X_o = the uncorrected count rate (c/30s)

B = Buildup Factor (unitless)

exp = base of natural logarithms

u = Linear Absorption Coefficient (cm^{-1})

x = absorber thickness (cm)

and further,

$$ux = u/p * x * p \qquad \textbf{Equation 2}$$

where

u/p = Mass Attenuation Coefficient (cm^2/g)

x = thickness of absorber (cm)

p = density of absorber (g/cm^3)

Radionuclide Emission Energies, Yields and Branching Ratios

The soil was assumed to contain only thorium radionuclides, specifically the principal gamma-ray emitters, Actinium-228, Lead-212 and Thallium-208 (see Radiological Health Handbook for the Thorium Decay Series and the principal gamma-ray emitters). The gamma-ray energies of these are given in Table 1.

When a radionuclide decays, it may not produce a gamma-ray with a given energy every time. The fraction of the time that a particular gamma-ray energy is produced is called the Yield. For example, referring to Table 1, Lead-212 (Pb-212) only produces a 238.6 kilo-electron volt (keV) gamma-ray 44.6% of the time. The Yields are found in Publication 38 of the International Commission on Radiological Protection, "Radionuclide Transformations, Energy and Intensity of Emissions" (ICRP 38)

Also, when a radionuclide decays, it may not produce the same decay product every time. For example, when Bismuth-212 decays, it produces Polonium-212 64.1% of the time and Thallium-208 35.9% of the time. These fractions, called Branching Ratios, are also found in ICRP 38.

The two actions together produce the final emission rate of the radionuclide. Thus, in Table 1, the product of the Gross Yield times the Branching Ratio gives the Net Yield. The Net Yield will be used in the calculation to be described in the section titled Adjustment for Yield.

Calculation of Mass Attenuation Coefficients

The Radiological Health Handbook contains tables with Mass Attenuation Coefficients by gamma ray energy for a water absorber (see Table 2). The Mass Attenuation Coefficients corresponding to reference gamma ray energies are listed in Table 1. Figure 1 shows that they are non-linear but, over small energy variations, Mass Attenuation Coefficients for energies between those listed (e.g., Pb-212, Ac-228, Tl-208) may be found by interpolation.

Interpolation for the Mass Attenuation Coefficients was done by two methods. As can be seen from Figure 1, the curve of Mass Attenuation Coefficient versus energy is quite concave so that there could not be any linear interpolation over many data points. It

was decided to try both a least squares fit over 3 points and an interpolation over two points. The results were compared.

Table 3 shows a Least Squares Fit over three points surrounding the thorium energy. The data for the Least Square Fit came from Table 2. For example, when the energy range was selected as 150 - 300 keV, the Mass Attenuation Coefficient points were those for 150, 200 and 300 keV. The Least Squares Fit calculation was done using the website at www.physics.csbsju.edu/stats/QF_NROW_form.html.

Each Least Squares Fit was done twice, once where two points were below the thorium gamma energy and again when two points were above the thorium gamma energy. Results for these two calculations were averaged. For example, with the thorium energy 238.6 keV, the Mass Attenuation Coefficients at 150, 200 and 300 keV were used in a Least Squares Fit . Then the Mass Attenuation Coefficients at 200, 300 and 400 keV were used in another Least Square Fit. The two results were averaged.

The Mass Attenuation Coefficient was also calculated by 2 Point Interpolation. Specifically, 238.6 keV is 38.6% of the difference between 200 and 300 keV. Thus, the Mass Attenuation Coefficient for 238.6 keV will be at 38.6% of the difference between 0.137 and 0.119 centimeters squared per gram (cm^2/g).

The results from these two methods are given in Table 4. The two methods compare very well. The results of the 2 Point Interpolation Method were used in the rest of the calculations because it was felt the method gave results that would correspond better to the exact coefficient.

Calculation of Linear Absorption Coefficients

Mass Attenuation Coefficients can be used to calculate Linear Absorption Coefficients by Equation 2. Using the two cases requested by the On-Scene Coordinator, 3 inches of water absorber and 1.5 inches of water absorber, the coefficients were calculated and tabulated in Table 11.

Calculation of Buildup Factors

The Linear Absorption Coefficients can be used in data from the Radiological Health Handbook to obtain Buildup Factors corresponding to the Thorium Decay Series gamma-ray emission energies.

Interpolation for the Buildup Factors was complicated because there are no listed Buildup Factors for energies less than 500 keV and Linear Absorption Coefficients less than one. These had to be interpolated.

First, when the thickness of the absorber is zero (ux = 0) the Buildup Factor must be 1. This is apparent from Equation 1 since X must equal X_0 and exp (-ux) equals 1 when ux is 0. This gives all the Buildup Factors for ux = 0 as 1.

Second, when the emission energy is zero, the Buildup Factor must be interpolated. Tables 9 and 10 provide data from the Radiological Health Handbook. Figures 6 and 7 show that linear extrapolation can be used to obtain the Buildup Factors at zero emission energy. This can be done by creating an equation for a line using the two lowest energies (500, 1000 keV) and extrapolating to zero energy. This gives the Buildup Factors for zero emission energy at ux = 1 and ux = 2.

Third, the Buildup Factors for the Linear Absorption Coefficient corresponding to a particular emission energy can be found by the Least Squares method. For example, the Linear Absorption Coefficient is 0.99100 for an Emission Energy of 238.6 keV (see Table 11). What is needed is the corresponding Buildup Factor.

The Least Square method is found at www.physics.csbsju.edu/stats/QF_NROW_form.html.

By example, Least Squares was applied (see Table 12) at zero energy, Linear Attenuation Coefficients ux = 0, 1, 2 and Buildup Factors B = 1, 3.00, 5.19, respectively, to obtain the line equation with intercept, a = 0.968 and slope, b = 2.10. Using ux = 0.99100 in this linear equation (B = a + b * ux), the corresponding Buildup Factor is 3.05. This value should be slightly less than 3.00, as shown by the pattern from ux = 0 to ux = 2. The difference is believed to be due to roundoff errors. This method was used to obtain Buildup Factors for emission energies of 0, 500, 1000, 2000, 3000 keV.

Fourth, the Buildup Factor for the emission and Linear Attenuation Coefficient of concern (the darkly boxed numbers on the left side of Tables 12 - 19) was obtained by interpolation.

Again, by example, using Table 12, the Buildup Factors for emission energies of 0 and 500 keV, are 3.05 and 2.62 at a Linear Attenuation Coefficient of 0.99100. These fit a line with intercept a = 3.05 and slope b = -0.000858 (see lower right of Table 12) and give the Buildup Factor, B = 2.84 at ux = 0.99100 (B = a + b * ux).

By these four methods, all the Buildup Factors necessary to complete the calculation were obtained. The data and calculation results are found in Tables 12 - 19 and the resulting Buildup Factors at the thorium emission energies are boxed and tabulated in Table 11.

Adjustment to Cleanup Criterion

When calibrations were done by STS Consultants for the downhole logging probes, the criterion was based on 7.2 pCi/g. Since the cleanup criterion for Lakeshore East is 7.1 pCi/g, a slight adjustment had to be made by ratioing (7.1/7.2). The adjusted count rate is 5321 counts per 30 seconds. This calculation can be found below Table 20.

Adjustment for Yield

Since the adjustment for count rate is energy dependent, it was necessary to find out what fraction of the total count rate corresponded to each emission energy.

First, the fraction of each radioactive decay corresponding to a thorium gamma-ray energy was found. For example, when lead-212 decays, a gamma-ray with an energy of 238.6 keV is emitted 44.6% of the time. These values, called Net Yields, are tablulated in Table 1 and repeated in Tables 20 and 21.

The total Yield is the sum of the individual Yields. Table 20 shows the total Net Yield for the Thorium Decay Series is 1.82 emissions. Below Table 18 a calculation is made that shows, at the cleanup criterion level of 5321 counts per 30 seconds, each emission is 2926 counts per 30 seconds. When this number is multiplied by the Net Yields, the count rate corresponding to the cleanup criterion is found. These are tabulated in Table 21 under Column C. As a check, the column was added and agreed exactly.

Changes in Exposure Rate Due to Absorption and Buildup

The equation listed at the beginning of this attachment can be adjusted to give the ratio of the initial count rate to the count rate after absorption and buildup.

$$\mathbf{X / X_o = B \exp(-[u/p] * x * p)} \qquad \textbf{Equation 3}$$

where

X / X_o = ratio of initial count rate to count rate after absorption and buildup (unitless)

B = Buildup Factor (unitless)

exp = base of natural logarithms

u/p = Mass Attenuation Coefficient (cm^2)

x = thickness of absorber (cm)

p = density of absorber (g/cm^3)

Table 20 shows the input factors for this calculation at each energy and gives the ratio in the far right column.

Adjusted Count Rate

In Table 21 the initial count rates, by energy, are listed in Column C. When these are mulitiplied by the ratios, X / X_o, in Column D the adjusted count rate by energy is obtained in Column E. The sum of the adjusted, energy dependent, count rates is 5336 counts per 30 seconds. This is slightly more, rather than less, than the initial count rate. This difference is believed to be due to roundoff error in the calculations. The final result is boxed at the end of this calculation.

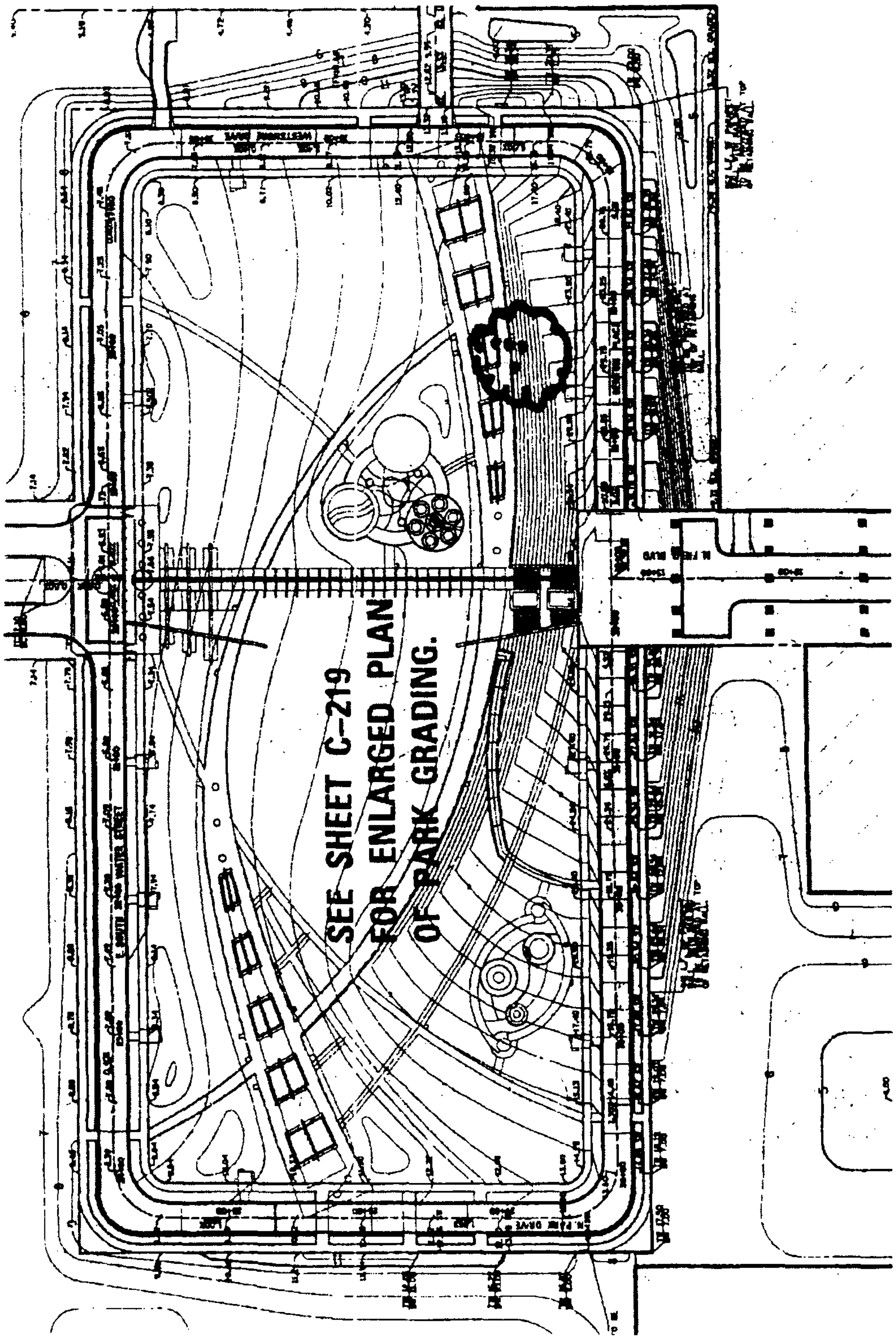
Conclusions

For 3 inches of water, the adjusted count rate is 5336 counts per 30 seconds compared to a no-water value of 5321 counts per 30 seconds. The difference is believed due to *roundoff error in the calculations.* Effectively, the 3 inches of water does not appreciably change the count rate.

For 1.5 inches of water, the adjusted count rate is 5216 counts per 30 seconds compared to a no-water value of 5321 counts per 30 seconds. The adjusted value is less than the no water value as would be expected. It is less, rather than greater, than the value for 3 inches of water. However, the values are close enough that the difference is believed to be due to roundoff error.

Effectively, the water has little to no effect on the measured count rates for downhole gamma logging. With these new values, there are no downhole logging data that exceed the equivalent cleanup criterion of 7.1 pCi/g.

SITE MAP WITH BORING LOCATONS



TOTAL P.03

DATA , CALCULATIONS, AND FIGURES
FOR CASES WITH

3 INCHES OF WATER
AND
1.5 INCHES OF WATER

BETWEEN EARTH AND DETECTOR

(INSERT EXCEL SPREADSHEETS)

LAKESHORE EAST, CALCULATIONS OF IMPACT ON GAMMA COUNT RATE
WITH WATER ABSORBER

CALCULATION FOR 3 INCHES---Tables 1 to 21, Figures 1 to 7
CALCULATION FOR 1.5 INCHES---Tables 22 to 42, Figures 8 to 14

Tables and Figures for 1.5 inches calculation are found below those for the 3 inches calculation on this spreadsheet

Table 1: Thorium Gamma Emission
Energies and Yields

Radio-nulclide	Emission Energies (keV)	Gross Yield (unitless)	Branching Ratio (fraction)	Net Yield (unitless)
Pb-212	238.6	0.446	1.000	0.446
Ac-228	338.4	0.120	1.000	0.120
Tl-208	510.8	0.216	0.359	0.078
Tl-208	583.1	0.858	0.359	0.308
Tl-208	860.4	0.120	0.359	0.043
Ac-228	911.1	0.290	1.000	0.290
Ac-228	968.9	0.175	1.000	0.175
Tl-208	2615	0.998	0.359	0.359

From: Publication 38
International Commission on
Radiological Protection
"Radionuclide Transformations,
Energy and Intensity of
Emissions"

Table 2: Mass Attenuation Coefficients

Emission Energy (keV)	Mass Attenuation Coefficient (cm^2/g)
100	0.171
150	0.151
200	0.137
300	0.119
400	0.106
500	0.0968
600	0.0896
800	0.0786
1000	0.0707
1500	0.0575
2000	0.0494
3000	0.0397
4000	0.0340

From: Radiological Health Handbook

Figure 1: Mass Attenuation Coefficients versus Gamma Emission Energy

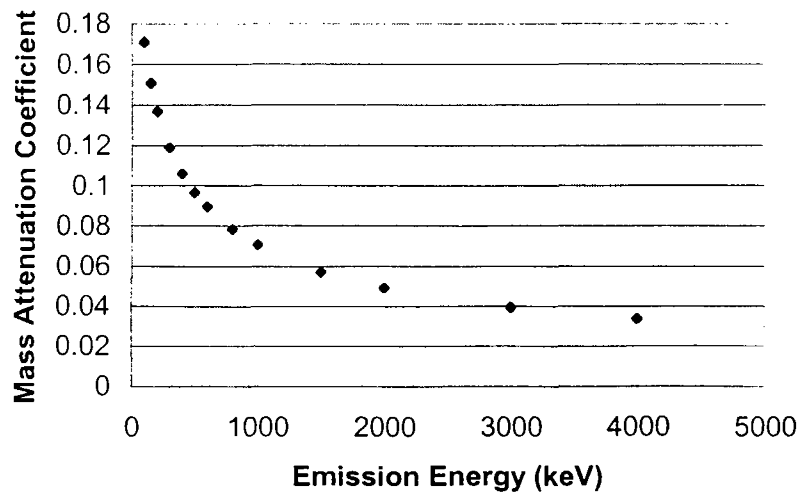


Table 3: Least Squares Fit for Mass Attenuation Coefficient

Energy Range for Least Squares Fit (keV)			Least Squares Fit				Emission Energy (keV)		Mass Attenuation Coefficient (cm2/g)	Mean Mass Attenuation Coefficient (cm2/g)
			a	+	b	*		=		
150	-	300	0.181	+	-2.086E-04	*	238.6	=	0.131	0.131
200	-	400	0.167	+	-1.550E-04	*	238.6	=	0.130	
200	-	400	0.167	+	-1.550E-04	*	338.4	=	0.115	0.114
300	-	500	0.152	+	-1.110E-04	*	338.4	=	0.114	
400	-	600	0.152	+	-1.110E-04	*	510.8	=	0.095	0.095
500	-	800	0.126	+	-5.986E-05	*	510.8	=	0.095	
400	-	600	0.138	+	-8.200E-05	*	583.1	=	0.090	0.091
500	-	800	0.126	+	-5.986E-05	*	583.1	=	0.091	
600	-	1000	0.117	+	-4.725E-05	*	860.4	=	0.076	0.076
800	-	1500	0.101	+	-2.942E-05	*	860.4	=	0.076	
600	-	1000	0.117	+	-4.725E-05	*	911.1	=	0.074	0.074
800	-	1500	0.101	+	-2.942E-05	*	911.1	=	0.074	
600	-	1000	0.117	+	-4.725E-05	*	968.9	=	0.071	0.072
800	-	1500	0.101	+	-2.942E-05	*	968.9	=	0.072	
1500	-	3000	0.07391	+	-1.156E-05	*	2615	=	0.044	0.044
2000	-	4000	0.06413	+	-7.70E-06	*	2615		0.044	

Table 4: Mass Attenuation Coefficient by 2 Point Interpolation and Comparison to Mean Mass Attenuation Coefficient by Least Squares Fit

Energy (keV)	Mass Attenuation Coefficient---By 2 Point Interpolation (cm2/g)	Mean Mass Attenuation Coefficient---By Least Squares Fit (cm2/g)
200	0.137	
238.6	**0.130**	0.131
300	0.119	
300	0.119	
338.4	**0.114**	0.114
400	0.106	
500	0.0968	
510.8	**0.0960**	0.0954
600	0.0896	
500	0.0968	
583.1	**0.0908**	0.0906
600	0.0896	
800	0.0786	
860.4	**0.0762**	0.0760
1000	0.0707	
800	0.0786	
911.1	**0.0742**	0.0741
1000	0.0707	
800	0.0786	
968.9	**0.0719**	0.0719
1000	0.0707	
2000	0.0494	
2615	**0.0434**	0.0438
3000	0.0397	

Table 5: Linear Absorption Coefficient and Buildup Factor For 500 keV

Emission Energy (keV)	Linear Absorption Coefficient ux (unitless)	Buildup Factor B (unitless)
500	1	2.63
	2	4.29
	4	9.05
	7	20.0
	10	35.9

Figure 2: Linear Absorption Coefficient versus Buildup Factor for 500 keV

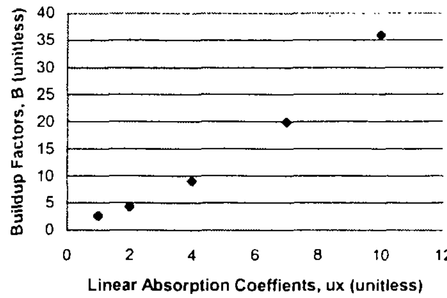


Table 6: Linear Absorption Coefficient and Buildup Factor For 1000 keV

Emission Energy (keV)	Linear Absorption Coefficient ux (unitless)	Buildup Factor B (unitless)
1000	1	2.26
	2	3.39
	4	6.27
	7	11.5
	10	18.0

Figure 3: Linear Absorption Coefficient versus Buildup Factor for 1000 keV

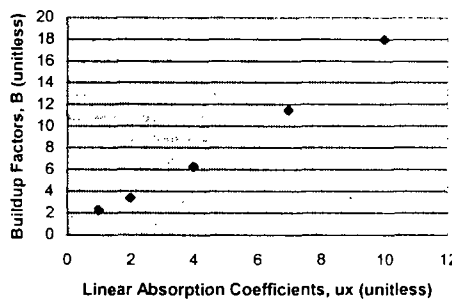


Table 7: Linear Absorption Coefficient and Buildup Factor For 2000 keV

Emission Energy (keV)	Linear Absorption Coefficient ux (unitless)	Buildup Factor B (unitless)
2000	1	1.84
	2	2.63
	4	4.28
	7	6.96
	10	9.87

Figure 4: Linear Absorption Coefficient versus Buildup Factor for 2000 keV

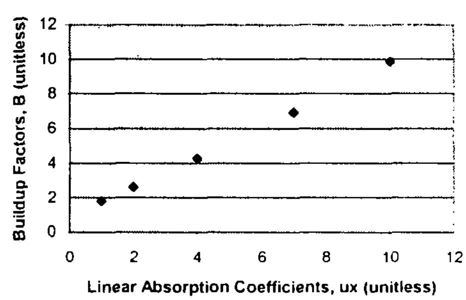


Table 8: Linear Absorption Coefficient and Buildup Factor For 3000 keV

Emission Energy (keV)	Linear Absorption Coefficient ux (unitless)	Buildup Factor B (unitless)
3000	1	1.69
	2	2.31
	4	3.57
	7	5.51
	10	7.48

Figure 5: Linear Absorption Coefficient versus Buildup Factor for 3000 keV

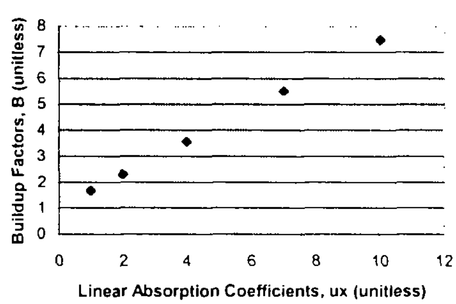
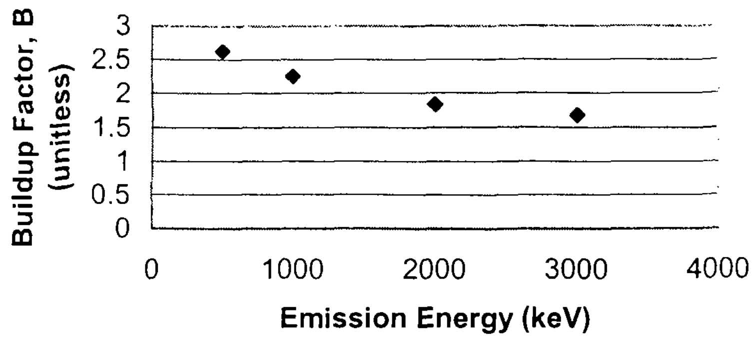


Table 9: E Buildup Factor by Energy, ux = 1

Emission Energy (keV)	Buildup Factor for ux =1 (unitless)
500	2.63
1000	2.26
2000	1.84
3000	1.69

Figure 6: Buildup Facts by Energy for ux = 1



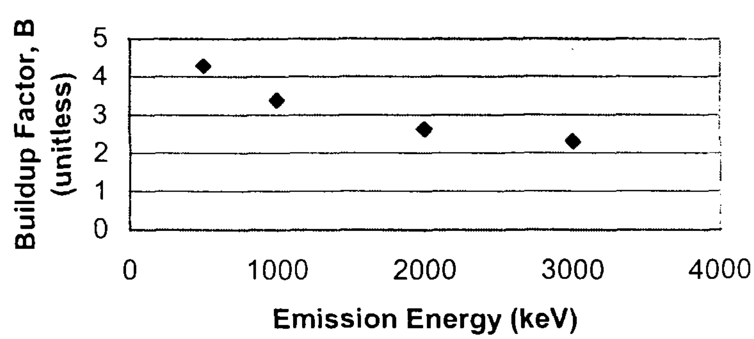
extrapolated to E = 0 keV using E = 500, 1000 keV

a +	b *	E =	B
3.00	-0.00074	0	3.00

Table 10: Buildup Factor by Energy, ux = 2

Emission Energy (keV)	Buildup Factor for ux =2 (unitless)
500	4.29
1000	3.39
2000	2.63
3000	2.31

Figure 7: Buildup Facts by Energy for ux = 2



extrapolated to E = 0 keV using E = 500, 1000 keV

a +	b *	E =	B
5.19	-0.0018	0	5.19

Table 11: Interpolated Plane Monodirectional Source Buildup Factor

Emission Energy	Mean Emission Energy Mass Absorption Coefficient	Mean Emission Energy Linear Absorption Coefficient	Interpolated Plane Source Buildup Factor
	(u/p)	(ux)	(b)
(MeV)	(cm2/g)	(unitless)	(unitless)
238.6	0.130	0.99100	2.84
338.4	0.114	0.86874	2.54
510.8	0.0960	0.73169	2.19
583.1	0.0908	0.69202	2.08
860.4	0.0762	0.58075	1.78
911.1	0.0742	0.56549	1.74
968.9	0.0719	0.54809	1.69
2615	0.0434	0.33097	1.25

ux = u/p * x * p

where

x =	3	inches =	7.62	cm	
p =	1	g/cm3 =	1	g / cm3	

Buildup Factor Interpolations

Table 12: Buildup Factor Interpolations for 238.6 keV

	0	0.99100	1	2	a +	b *	ux	=		
0	1	**3.05**	3.00	5.19	0.968	2.10	0.99100	=	3.05	
238.6	1	$\boxed{2.84}$								
500	1	**2.62**	2.63	4.29	0.995	1.64	0.99100	=	2.62	By Least Squares
					3.05	-0.000858	238.6	=	2.84	By 2 points

Table 13: Buildup Factor Interpolations for 338.4 keV

	0	0.86874	1	2	a +	b *	ux	=		
0	1	**2.79**	3.00	5.19	0.968	2.10	0.86874	=	2.79	
338.4	1	$\boxed{2.54}$								
500	1	**2.42**	2.63	4.29	0.995	1.64	0.86874	=	2.42	By Least Squares
					2.79	-0.000745	338.4	=	2.54	By 2 points

Table 14: Buildup Factor Interpolations for 510.8 keV

	0	0.73169	1	2	a +	b *	ux	=		
500	1	**2.19**	2.63	4.29	0.995	1.64	0.73169	=	2.19	By Least Squares
510.8	1	$\boxed{2.19}$								
1000	1	**1.90**	2.26	3.39	1.02	1.20	0.73169	=	1.90	By Least Squares
					2.49	-0.000594	510.8	=	2.19	By 2 points

Table 15: Buildup Factor Interpolations for 583.1 keV

	0	0.69202	1	2	a +	b *	ux	=		
500	1	**2.13**	2.63	4.29	0.995	1.64	0.69202	=	2.13	By Least Squares
583.1	1	$\boxed{2.08}$								
1000	1	**1.85**	2.26	3.39	1.02	1.20	0.69202	=	1.85	By Least Squares
					2.41	-0.000559	583.1	=	2.08	By 2 points

Table 16: Buildup Factor Interpolations for 860.4 keV

	0	0.58075	1	2	a +	b *	ux	=		
500	1	**1.95**	2.63	4.29	0.995	1.64	0.58075	=	1.95	By Least Squares
860.4	1	$\boxed{1.78}$								
1000	1	**1.72**	2.26	3.39	1.02	1.20	0.58075	=	1.72	By Least Squares
					2.18	-0.000461	860.4	=	1.78	By 2 points

Table 17: Buildup Factor Interpolations for 911.1 keV

	0	0.56549	1	2	a +	b *	ux	=		
500	1	**1.92**	2.63	4.29	0.995	1.64	0.56549	=	1.92	By Least Squares
911.1	1	$\boxed{1.74}$								
1000	1	**1.70**	2.26	3.39	1.02	1.20	0.56549	=	1.70	By Least Squares
					2.15	-0.000448	911.1	=	1.74	By 2 points

Table 18: Buildup Factor Interpolations for 968.9 keV

	0	0.54809	1	2	a +	b *	ux	=		
500	1	**1.89**	2.63	4.29	0.995	1.64	0.54809	=	1.89	By Least Squares
968.9	1	$\boxed{1.69}$								
1000	1	**1.68**	2.26	3.39	1.02	1.20	0.54809	=	1.68	By Least Squares
					2.11	-0.000432	968.9	=	1.69	By 2 points

Table 19: Buildup Factor Interpolations for 2615 keV

	0	0.33097	1	2	a +	b *	ux	=		
2000	1	**1.28**	1.84	2.63	1.01	0.815	0.33097	=	1.28	By Least Squares
2615	1	$\boxed{1.25}$								
3000	1	**1.23**	1.69	2.31	1.01	0.655	0.33097	=	1.23	By Least Squares
					1.39	-0.000053	2615	=	1.25	By 2 points

Table 20: Ratio of Adjusted to Original Count Rate

Emission Energies (keV)	Interpolated Plane Source Buildup Factor (b) (unitless)	Emission Energy Mass Absorption Coefficient (u/p) (MeV)	Thickness of Water Absorber (x) (cm)	Density of Water (p) (g/cm3)	Net Yield (unitless)	Ratio, Absorbed Exposure Rate (unitless)
238.6	2.84	0.130	7.62	1	0.446	1.06
338.4	2.54	0.114	7.62	1	0.120	1.07
510.8	2.19	0.0960	7.62	1	0.078	1.05
583.1	2.08	0.0908	7.62	1	0.308	1.04
860.4	1.78	0.0762	7.62	1	0.043	1.00
911.1	1.74	0.0742	7.62	1	0.290	0.99
968.9	1.69	0.0719	7.62	1	0.175	0.98
2615	1.25	0.0434	7.62	1	0.359	0.90
					1.82	

Ratio = X / Xo = B exp(-[u/p] * x * p)

Total counts at 7.2 pCi/g 5396 counts / 30 seconds
Total counts at 7.1 pCi/g 5321

5321 / 1.82 = 2926 counts / 30 seconds

Table 21: Adjusted Count Rate for Cleanup Criterion

A	B	C	D	E	F
Emission Energy	Net Yield	Emission Rate by Energy	Ratio, Absorbed Exposure Rate	Adjusted Emission Rate by Energy	Ratio, Original Emission Rate to Adjusted Emission Rate
		2926 * Net Yield	**Table 20**	**Column C * Column D**	**Column E / Column C**
(keV)	(unitless)	(counts/30 sec)	(unitless)	(counts/30 sec)	(unitless)
238.6	0.446	1305	1.06	1378	1.056
338.4	0.120	351	1.07	374	1.066
510.8	0.078	227	1.05	239	1.053
583.1	0.308	902	1.04	941	1.043
860.4	0.043	126	1.00	126	0.997
911.1	0.290	849	0.99	838	0.988
968.9	0.175	512	0.98	501	0.978
2615	0.359	1049	0.90	940	0.896
	Total	5321	**Total**	5336	100.3%

Count rate equivalent to 7.1 pCi/g	=	5336 counts per 30 seconds

LAKESHORE EAST, CALCULATION OF IMPACT ON GAMMA COUNT RATE
WITH 1.5 INCHES OF WATER ABSORBER

Table 22: Thorium Gamma Emission
Energies and Yields

Radio-nulclide	Emission Energies (keV)	Gross Yield (unitless)	Branching Ratio (fraction)	Net Yield (unitless)
Pb-212	238.6	0.446	1.000	0.446
Ac-228	338.4	0.120	1.000	0.120
Tl-208	510.8	0.216	0.359	0.078
Tl-208	583.1	0.858	0.359	0.308
Tl-208	860.4	0.120	0.359	0.043
Ac-228	911.1	0.290	1.000	0.290
Ac-228	968.9	0.175	1.000	0.175
Tl-208	2615	0.998	0.359	0.359

From: Publication 38
International Commission on
Radiological Protection
"Radionuclide Transformations,
Energy and Intensity of
Emissions"

Table 23: Mass Attenuation Coefficients

Emission Energy (keV)	Mass Attenuation Coefficient (cm^2/g)
100	0.171
150	0.151
200	0.137
300	0.119
400	0.106
500	0.0968
600	0.0896
800	0.0786
1000	0.0707
1500	0.0575
2000	0.0494
3000	0.0397
4000	0.0340

From: Radiological Health Handbook

Figure 8: Mass Attenuation Coefficients versus Gamma Emission Energy

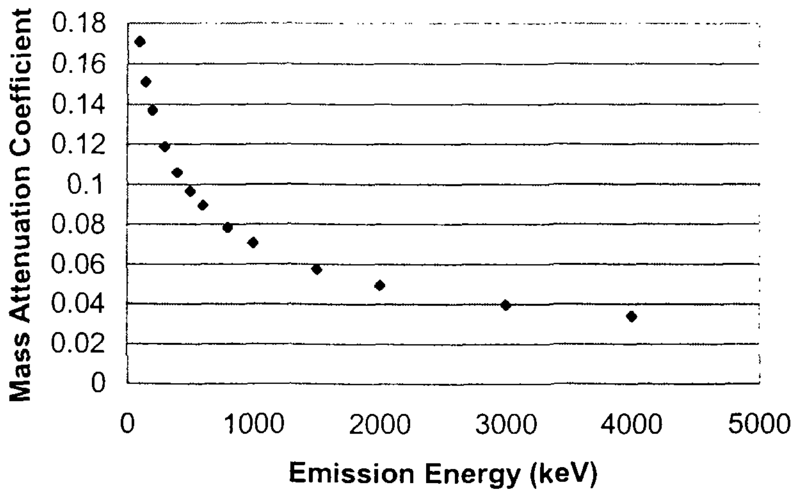


Table 24: Least Squares Fit for Mass Attenuation Coefficient

Energy Range for Least Squares Fit (keV)			Least Squares Fit				Emission Energy (keV)		Mass Attenuation Coefficient (cm2/g)	Mean Mass Attenuation Coefficient (cm2/g)
			a	+	b	*		=		
150	-	300	0.181	+	-2.086E-04	*	238.6	=	0.131	0.131
200	-	400	0.167	+	-1.550E-04	*	238.6	=	0.130	
200	-	400	0.167	+	-1.550E-04	*	338.4	=	0.115	0.114
300	-	500	0.152	+	-1.110E-04	*	338.4	=	0.114	
400	-	600	0.152	+	-1.110E-04	*	510.8	=	0.095	0.095
500	-	800	0.126	+	-5.986E-05	*	510.8	=	0.095	
400	-	600	0.138	+	-8.200E-05	*	583.1	=	0.090	0.091
500	-	800	0.126	+	-5.986E-05	*	583.1	=	0.091	
600	-	1000	0.117	+	-4.725E-05	*	860.4	=	0.076	0.076
800	-	1500	0.101	+	-2.942E-05	*	860.4	=	0.076	
600	-	1000	0.117	+	-4.725E-05	*	911.1	=	0.074	0.074
800	-	1500	0.101	+	-2.942E-05	*	911.1	=	0.074	
600	-	1000	0.117	+	-4.725E-05	*	968.9	=	0.071	0.072
800	-	1500	0.101	+	-2.942E-05	*	968.9	=	0.072	
1500	-	3000	0.07391	+	-1.156E-05	*	2615	=	0.044	0.044
2000	-	4000	0.06413	+	-7.70E-06	*	2615		0.044	

Table 25: Mass Attenuation Coefficient by 2 Point Interpolation and Comparison to Mean Mass Attenuation Coefficient by Least Squares Fit

Energy (keV)	Mass Attenuation Coefficient---By 2 Point Interpolation (cm2/g)	Mean Mass Attenuation Coefficient---By Least Squares Fit (cm2/g)
200	0.137	
238.6	**0.130**	0.131
300	0.119	
300	0.119	
338.4	**0.114**	0.114
400	0.106	
500	0.0968	
510.8	**0.0960**	0.0954
600	0.0896	
500	0.0968	
583.1	**0.0908**	0.0906
600	0.0896	
800	0.0786	
860.4	**0.0762**	0.0760
1000	0.0707	
800	0.0786	
911.1	**0.0742**	0.0741
1000	0.0707	
800	0.0786	
968.9	**0.0719**	0.0719
1000	0.0707	
2000	0.0494	
2615	**0.0434**	0.0438
3000	0.0397	

Table 26: Linear Absorption Coefficient and Buildup Factor For 500 keV

Emission Energy (keV)	ux	B
500	1	2.63
	2	4.29
	4	9.05
	7	20.0
	10	35 9

Figure 9: Linear Absorption Coefficient versus Buildup Factor for 500 keV

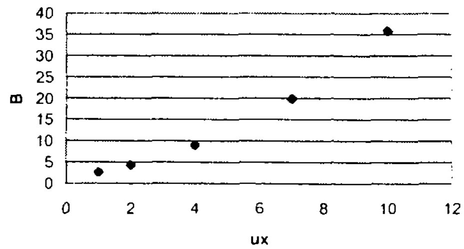


Table 27: Linear Absorption Coefficient and Buildup Factor For 1000 keV

Emission Energy (keV)	ux	B
1000	1	2.26
	2	3.39
	4	6.27
	7	11.5
	10	18.0

Figure 10: Linear Absorption Coefficient versus Buildup Factor for 1000 keV

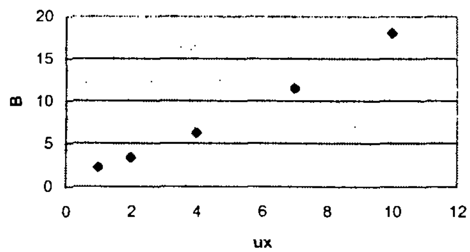


Table 28: Linear Absorption Coefficient and Buildup Factor For 2000 keV

Emission Energy (keV)	ux	B
2000	1	1.84
	2	2.63
	4	4.28
	7	6.96
	10	9.87

Figure 11: Linear Absorption Coefficient versus Buildup Factor for 2000 keV

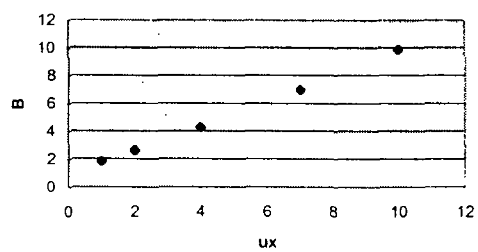


Table 29: Linear Absorption Coefficient and Buildup Factor For 3000 keV

Emission Energy (keV)	ux	B
3000	1	1.69
	2	2.31
	4	3.57
	7	5.51
	10	7 48

Figure 12: Linear Absorption Coefficient versus Buildup Factor for 3000 keV

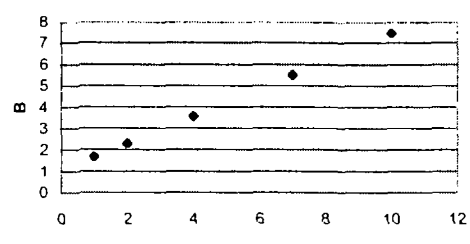
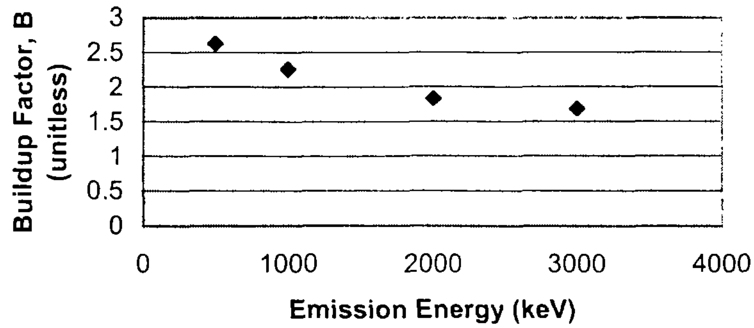


Table 30: Buildup Factor by Energy, ux = 1

Energy (keV)	Buildup Factor for ux =1
500	2.63
1000	2.26
2000	1.84
3000	1.69

Figure 13: Buildup Facts by Energy for ux = 1



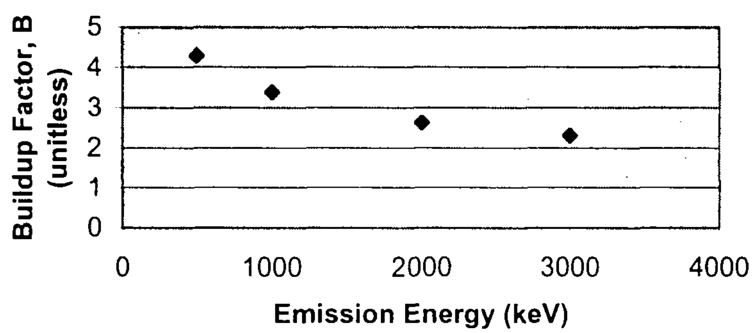
extrapolated to E = 0 keV using E = 500, 1000 keV

a +	b *	E =	B
3.00	-0.00074	0	3.00

Table 31: Buildup Factor by Energy, ux = 2

Energy (keV)	Buildup Factor for ux =2
500	4.29
1000	3.39
2000	2.63
3000	2.31

Figure 14: Buildup Facts by Energy for ux = 2



extrapolated to E = 0 keV using E = 500, 1000 keV

a +	b *	E =	B
5.19	-0.0018	0	5.19

Table 32: Interpolated Plane Monodirectional Source Buildup Factor

Emission Energy (MeV)	Mean Emission Energy Mass Absorption Coefficient (u/p) (cm2/g)	Mean Emission Energy Linear Absorption Coefficient (ux) (unitless)	Interpolated Plane Source Buildup Factor (b) (unitless)
238.6	0.130	0.49550	1.91
338.4	0.114	0.43437	1.76
510.8	0.0960	0.36585	1.59
583.1	0.0908	0.34601	1.54
860.4	0.0762	0.29038	1.40
911.1	0.0742	0.28275	1.38
968.9	0.0719	0.27405	1.35
2615	0.0434	0.16549	1.13

ux = u/p * x * p

where

x =	1.5	inches =	3.81	cm	
p =	1	g/cm3 =	1	g / cm3	

Buildup Factor Interpolations

Table 33: Buildup Factor Interpolations for 238.6 keV

	0	0.49550	1	2	a +	b *	ux	=		
0	1	2.01	3.00	5.19	0.968	2.1	0.49550	=	2.01	
238.6	1	**1.91**								
500	1	1.81	2.63	4.29	0.995	1.64	0.49550	=	1.81	By Least Squares
					2.01	-0.000402	238.6	=	1.91	By 2 points

Table 34: Buildup Factor Interpolations for 338.4 keV

	0	0.43437	1	2	a +	b *	ux	=		
0	1	1.88	3.00	5.19	0.968	2.1	0.43437	=	1.88	
338.4	1	**1.76**								
500	1	1.71	2.63	4.29	0.995	1.64	0.43437	=	1.71	By Least Squares
					1.88	-0.000346	338.4	=	1.76	By 2 points

Table 35: Buildup Factor Interpolations for 510.8 keV

	0	0.36585	1	2	a +	b *	ux	=		
500	1	1.59	2.63	4.29	0.995	1.64	0.36585	=	1.59	By Least Squares
510.8	1	**1.59**								
1000	1	1.46	2.26	3.39	1.02	1.20	0.36585	=	1.46	By Least Squares
					1.73	-0.000272	510.8	=	1.59	By 2 points

Table 36: Buildup Factor Interpolations for 583.1 keV

	0	0.34601	1	2	a +	b *	ux	=		
500	1	1.56	2.63	4.29	0.995	1.64	0.34601	=	1.56	By Least Squares
583.1	1	**1.54**								
1000	1	1.44	2.26	3.39	1.02	1.20	0.34601	=	1.44	By Least Squares
					1.69	-0.000254	583.1	=	1.54	By 2 points

Table 37: Buildup Factor Interpolations for 860.4 keV

	0	0.29038	1	2	a +	b *	ux	=		
500	1	1.47	2.63	4.29	0.995	1.64	0.29038	=	1.47	By Least Squares
860.4	1	**1.40**								
1000	1	1.37	2.26	3.39	1.02	1.20	0.29038	=	1.37	By Least Squares
					1.57	-0.000206	860.4	=	1.40	By 2 points

Table 38: Buildup Factor Interpolations for 911.1 keV

	0	0.28275	1	2	a +	b *	ux	=		
500	1	1.46	2.63	4.29	0.995	1.64	0.28275	=	1.46	By Least Squares
911.1	1	**1.38**								
1000	1	1.36	2.26	3.39	1.02	1.20	0.28275	=	1.36	By Least Squares
					1.56	-0.000199	911.1	=	1.38	By 2 points

Table 39: Buildup Factor Interpolations for 968.9 keV

	0	0.27405	1	2	a +	b *	ux	=		
500	1	1.44	2.63	4.29	0.995	1.64	0.27405	=	1.44	By Least Squares
968.9	1	**1.35**								
1000	1	1.35	2.26	3.39	1.02	1.20	0.27405	=	1.35	By Least Squares
					1.54	-0.000191	968.9	=	1.35	By 2 points

Table 40: Buildup Factor Interpolations for 2615 keV

	0	0.16549	1	2	a +	b *	ux	=		
2000	1	1.14	1.84	2.63	1.01	0.815	0.16549	=	1.14	By Least Squares
2615	1	**1.13**								
3000	1	1.12	1.69	2.31	1.01	0.655	0.16549	=	1.12	By Least Squares
					1.20	-0.000026	2615	=	1.13	By 2 points

Table 41: Ratio of Adjusted to Original Count Rate

Emission Energies (keV)	Interpolated Plane Source Buildup Factor (b) (unitless)	Emission Energy Mass Absorption Coefficient (u/p) (MeV)	Thickness of Water Absorber (x) (cm)	Density of Water (p) (g/cm3)	Net Yield (unitless)	Ratio, Absorbed Exposure Rate (unitless)
238.6	1.91	0.130	3.81	1	0.446	1.17
338.4	1.76	0.114	3.81	1	0.120	1.14
510.8	1.59	0.0960	3.81	1	0.078	1.10
583.1	1.54	0.0908	3.81	1	0.308	1.09
860.4	1.40	0.0762	3.81	1	0.043	1.05
911.1	1.38	0.0742	3.81	1	0.290	1.04
968.9	1.35	0.0719	3.81	1	0.175	1.03
2615	1.13	0.0434	3.81	1	0.359	0.96
					1.82	

Ratio = X / Xo = B exp(-[u/p] * x * p)

Total counts at 7.2 pCi/g 5396 counts / 30 seconds
Total counts at 7.1 pCi/g 5321

5321 / 1.82 = 2926 counts / 30 seconds

Table 42: Adjusted Count Rate for Cleanup Criterion

A	B	C	D	E	F
Emission Energy	Net Yield	Emission Rate by Energy	Ratio, Absorbed Exposure Rate	Adjusted Emission Rate by Energy	Ratio, Original Emission Rate to Adjusted Emission Rate
		2926 * Yield	Table 20	Column C * Column D	Column E / Column C
(keV)	(unitless)	(counts/30 sec)	(unitless)	(counts/30 sec)	(unitless)
238.6	0.446	1305	1.17	1521	1.165
338.4	0.120	351	1.14	401	1.142
510.8	0.078	227	1.10	251	1.104
583.1	0.308	902	1.09	984	1.090
860.4	0.043	126	1.05	132	1.045
911.1	0.290	849	1.04	881	1.038
968.9	0.175	512	1.03	527	1.030
2615	0.359	1049	0.96	1004	0.956
	Total	5321	Total	5699	107.1%

Count rate equivalent to 7.1 pCi/g	=	5699 counts per 30 seconds